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Large Hadron Accelerators: Operation, Improvements, Upgrades

Case for Fermilab, CERN, BNL, JPARC and ORNL

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Dec 2018 – Jan 2019

High Level : Cost to Operate vs TPC - ILC Example

APPENDIX A: ILC250 PROJECT COSTS

	TDR: ILC500 [B ILCU] (Estimated by GDE)	ILC250 [B ILCU] (Estimated by LCC)	Conversion to: [B JPY] (Reported to MEXT/SCJ)
Accelerator Construction: sum	**n/a**	**n/a**	**635.0 ~ 702.8**
Value: sub-sum	7.98	4.78 ~ 5.26	515.2 ~ 583.0
Tunnel & building	1.46	1.01	111.0 ~ 129.0
Accelerator & utility	6.52	3.77 ~ 4.24	404.2 ~ 454.0
Labor: Human Resource	22.9 M person-hours (13.5 K person-years)	17.2 M person-hours (10.1 K person-years)	119.8
Detector Construction: sum	**n/a**	**n/a**	**100.5**
Value: Detectors (SiD+ILD)	315+392	315+392	76.6
Labor: Human Resource (SiD + ILD)	748+1,400 person-years	748+1,400 person-years	23.9
Operation/year (Acc.) : sum	**n/a**	**n/a**	**36.6 ~ 39.2**
Value: Utilities/Maintenance	390	290 ~ 316	29.0 ~ 31.6
Labor: Human Resource	850 FTE	638 FTE	7.6
Others (Acc. Preparation)	**n/a**	**n/a**	**23.3**
Uncertainty	**25%**	**25%**	**25%**
Contingency	**10%**	**10%**	**10%**
Decommission	**n/a**	**n/a**	**Equiv. to 2-year op. cost**

http://www.mext.go.jp/component/b_menu/shingi/toushin/__icsFiles/afieldfile/2018/09/20/1409220_2_1.pdf

FIG. 7. Costs of the ILC250 project in ILCU as evaluated by the Linear Collider Collaboration (LCC), converted to JPY and re-evaluated by KEK, and summarised in the MEXT ILC Advisory Panel report, in July, 2018.

39.2/702.8= **5.6%** / year or “lifetime” τ of **18 yrs** = 1/5.6%

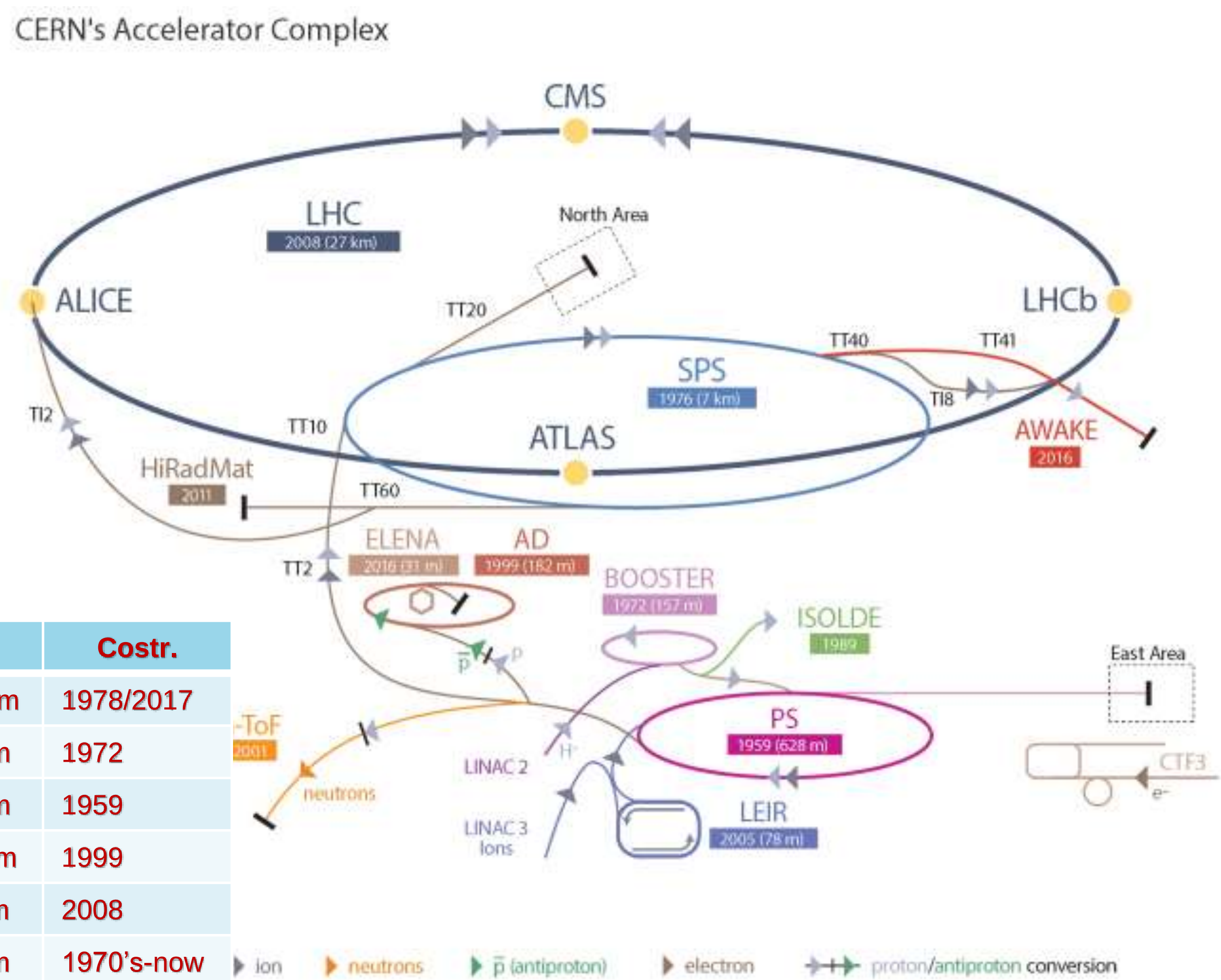
Cost to Operate vs TPC : LHC, RHIC, Fermilab, JPARC and SNS

In todays' $$ - TPC:		Ops $$/yr	τ, yrs
LHC+SPS+PS+PSB	~11 B$ ± 4	~700M$	15
RHIC+AGS+Boo+Li	~4.2B$ ± 1.5	~170M$	25
MI+RR+B+Linac+MC	~4.0B$ ± 1.4	~110M$	36
JPARC (L+RCS+MR)	~1.5B$ ± 0.2	~190M$	8
SNS (Linac + Ring)	~1.4B$ ± 0.3	~200M$	7

A phenomenological cost model for high energy particle accelerators

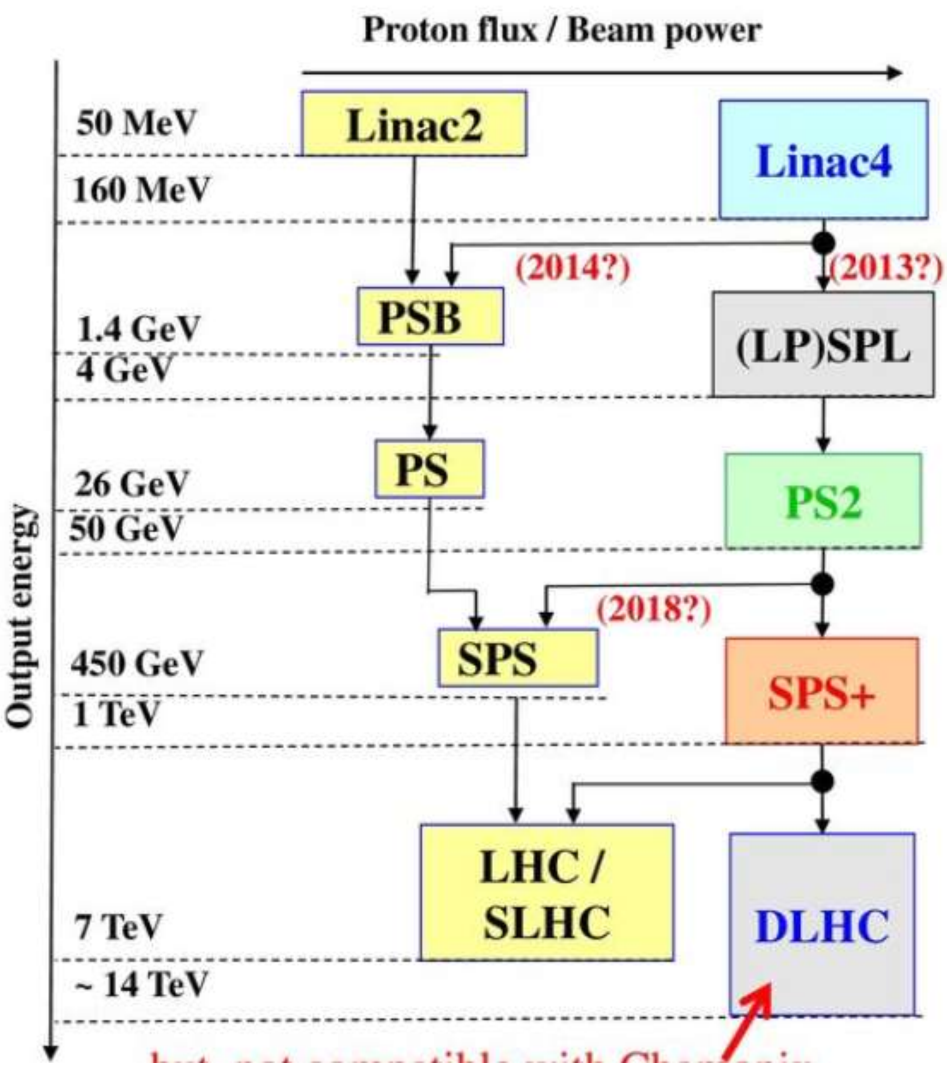
2014 JINST 9 T07002

CERN (1)



	E	L	Costr.
Linac 2/4	52/160 MeV	~100m	1978/2017
PSB	1.4 GeV	160 m	1972
PS	26 GeV	630 m	1959
SPS	0.45 GeV	6.9 km	1999
LHC	13 TeV	27 km	2008
Beamlines	1-450 GeV	~8 km	1970's-now
Upgr: HL-LHC	14 TeV	~1 km	2025
Upgr :HE-LHC/FCC	25-100TeV	?	ca 2035
Upgr: beamlines	3 TeV	?	ca 2035

LHC Injector Upgrades (LIU): 2014-2019 , ~200MCHF



Motivation

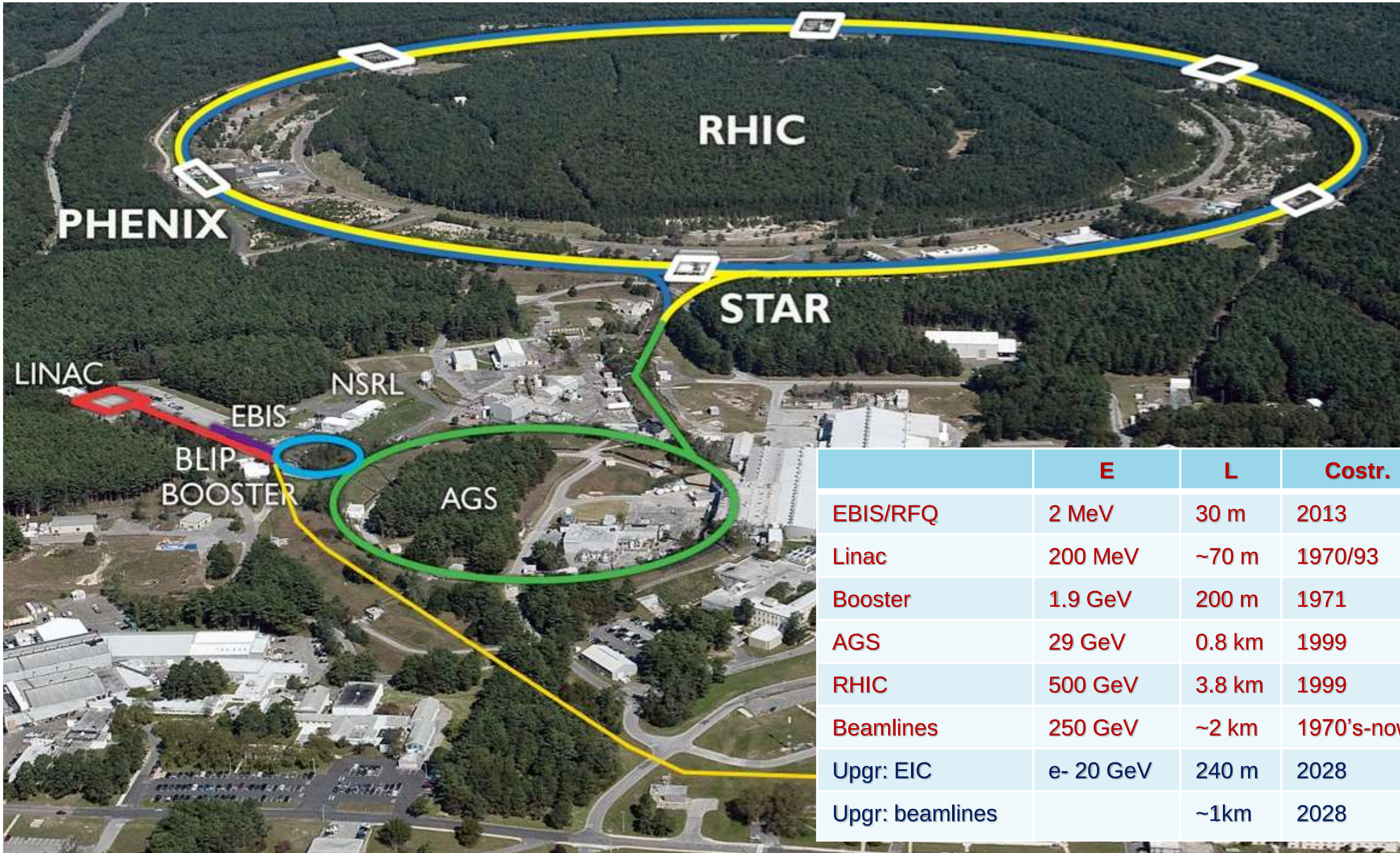
1. **Reliability: Present CERN accelerators too old ⇒need for new accelerators designed for the needs of SLHC**
2. **Performance: Increase of brightness of the beam in LHC to allow for phase 2 of the LHC upgrade. ⇒need to increase the injection energy in the synchrotrons**

LP-SPL: Low Power-Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
sLHC: “Super-luminosity” LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: “Double energy” LHC (1 to ~14 TeV)

CERN (3): LIU 2014-2019 (~200MCHF)

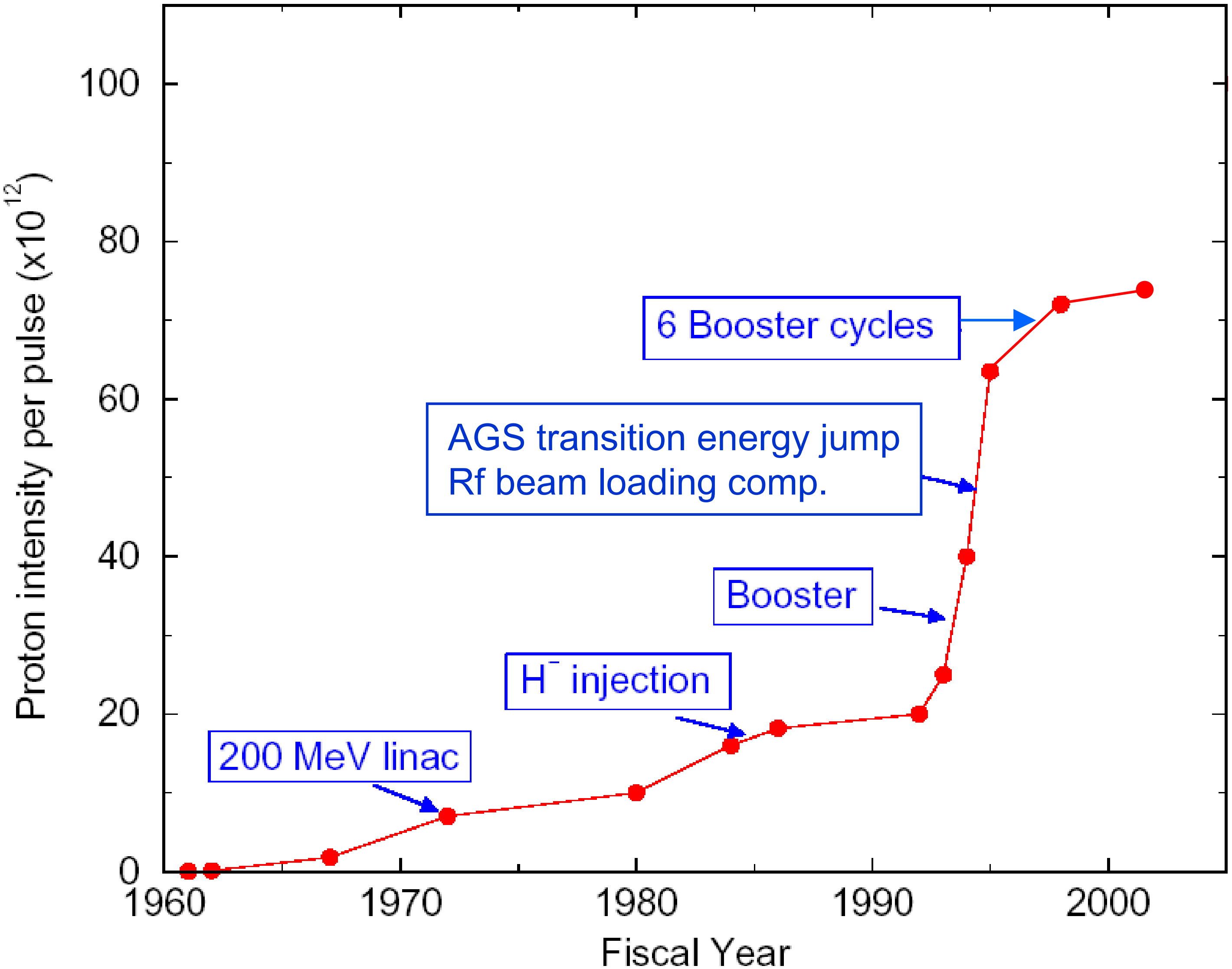
- The replacement of Linac2, which accelerates protons to 50 MeV, with Linac4, providing 160 MeV H- ions;
- Proton Synchrotron Booster (PSB): New 160 MeV H- charge exchange injection, acceleration to 2 GeV from current 1.4 GeV with new power supply and RF system;
- Proton Synchrotron (PS): New 2 GeV injection, broadband longitudinal feedback;
- Super Proton Synchrotron (SPS): Upgrade of the 200 MHz RF system, impedance reduction and e-cloud mitigation, new beam dump and protection devices.

BNL(1)



	E	L	Costr.
EBIS/RFQ	2 MeV	30 m	2013
Linac	200 MeV	~70 m	1970/93
Booster	1.9 GeV	200 m	1971
AGS	29 GeV	0.8 km	1999
RHIC	500 GeV	3.8 km	1999
Beamlines	250 GeV	~2 km	1970's-now
Upgr: EIC	e- 20 GeV	240 m	2028
Upgr: beamlines		~1km	2028

AGS Upgrades : 4 Decades



Fermilab

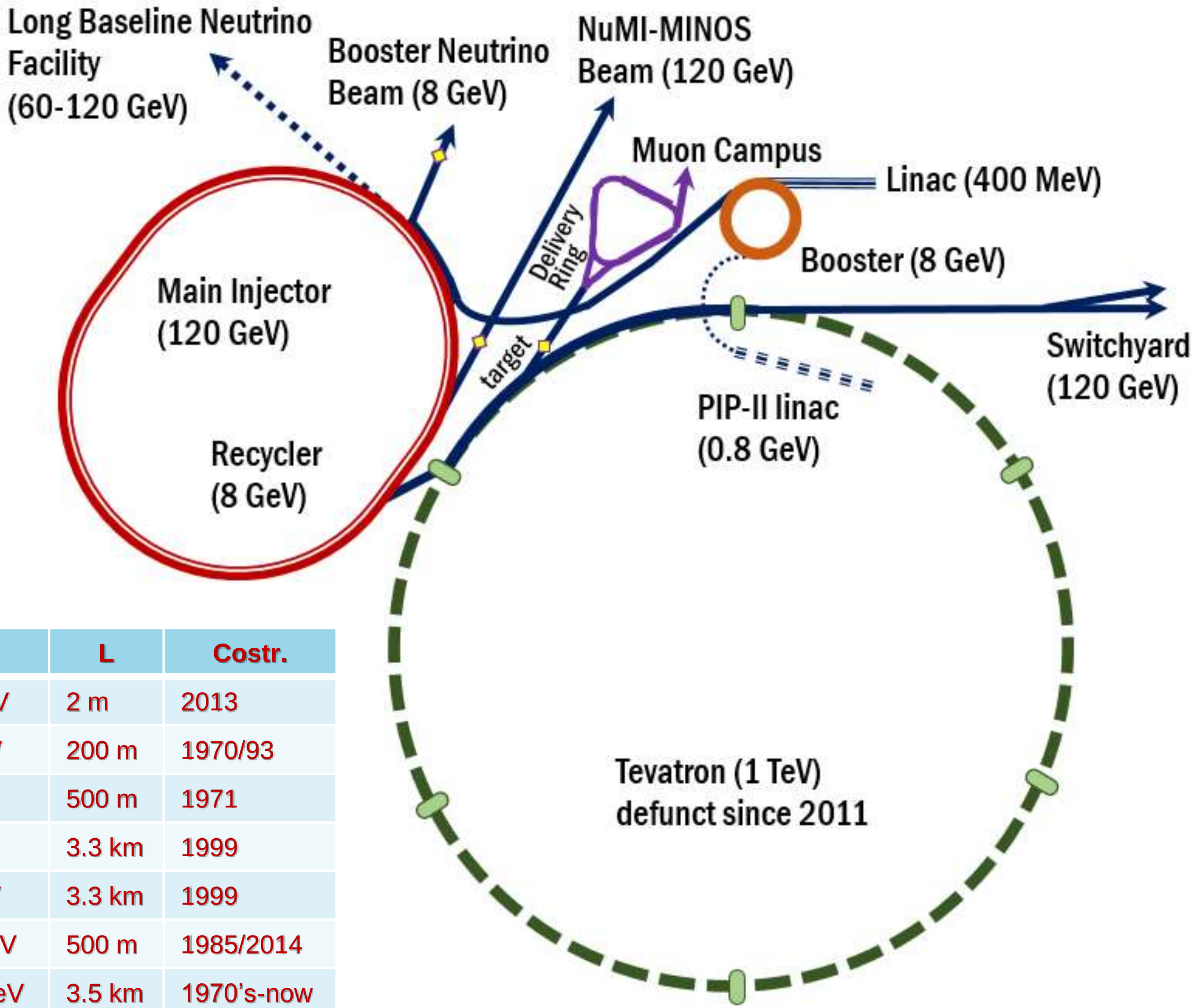
RHIC Luminosity Improvements/Upgrades : Past Decade

- Polarization improvements
  - Snakes, polarimeters, etc
- EBIS (Electron Bean Ion Source)
  - better ion source (~x 10 in currents)
- Bunched beam stochastic cooling
  - Fermilab hardware for ions → ~x3 in integrated *L*
- Electron Lenses
  - (Tevatron like) for HO BBC → ~x2 in integrated *L*
- Low energy electron cooling – to collide low energy ions with high(er) lumiunosity:
  - Coherent e- cooling (suspended)
  - Photoinjector based 2.6 MeV e-cooler (installed)

Other Improvements Under Discussion or Under Way

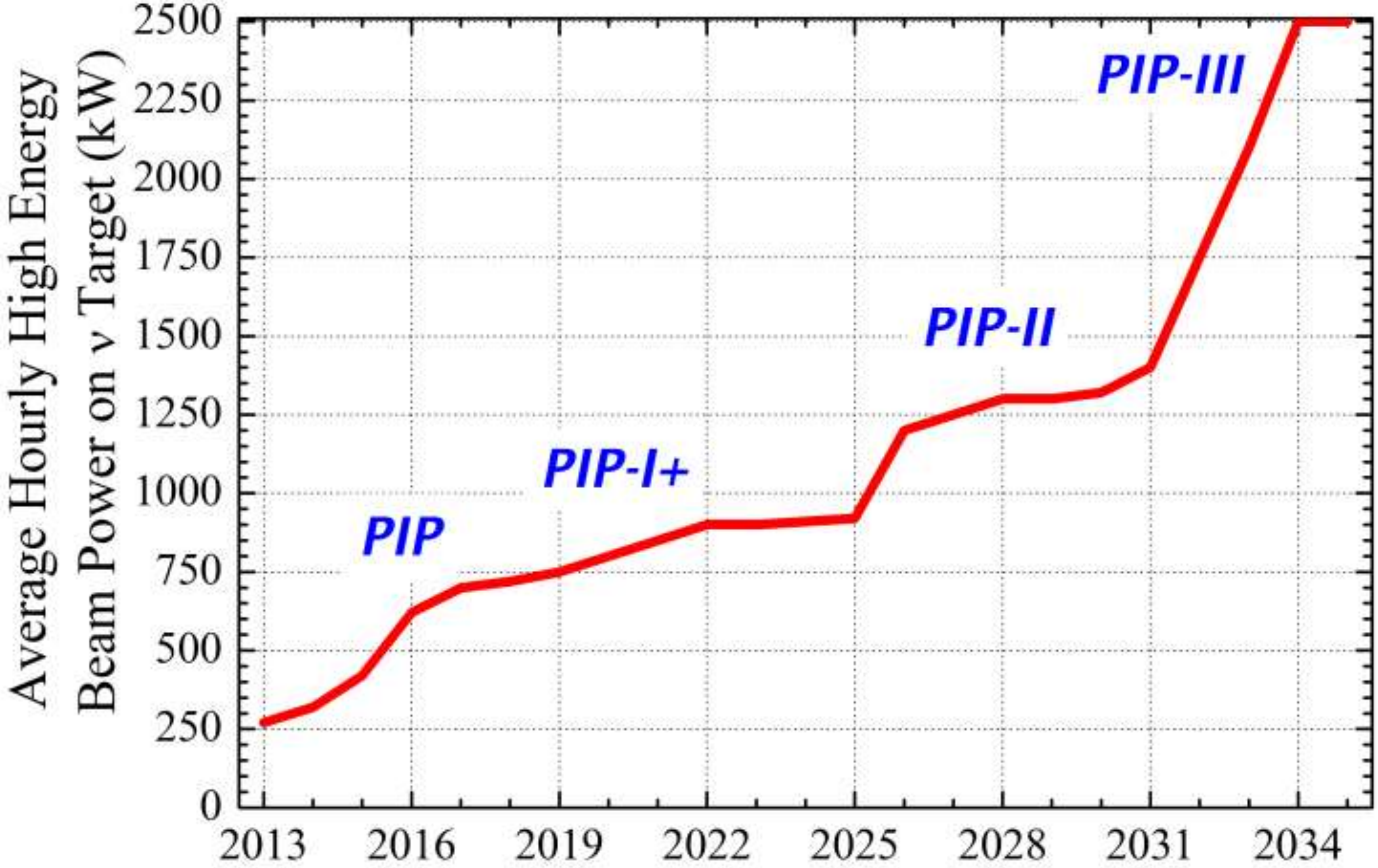
- 200 MeV Linac: pulse length doubling for increased isotope production - proposal formulated, waiting for funding)
- Extended EBIS (2 superconducting solenoids in series instead of 1 now) - under way, completion by Dec 2020
  - will yield ~40% more Au beam (longer trap length)
  - will have gas cell for He-3 polarization
  - will give better performance for other gas elements (NASA interest)
- Booster
  - AC dipole installation for polarized He-3 acceleration (hopefully before RHIC Run-19)
- AGS
  - polarized He-3 acceleration after we have beam through Booster

Fermilab (1)

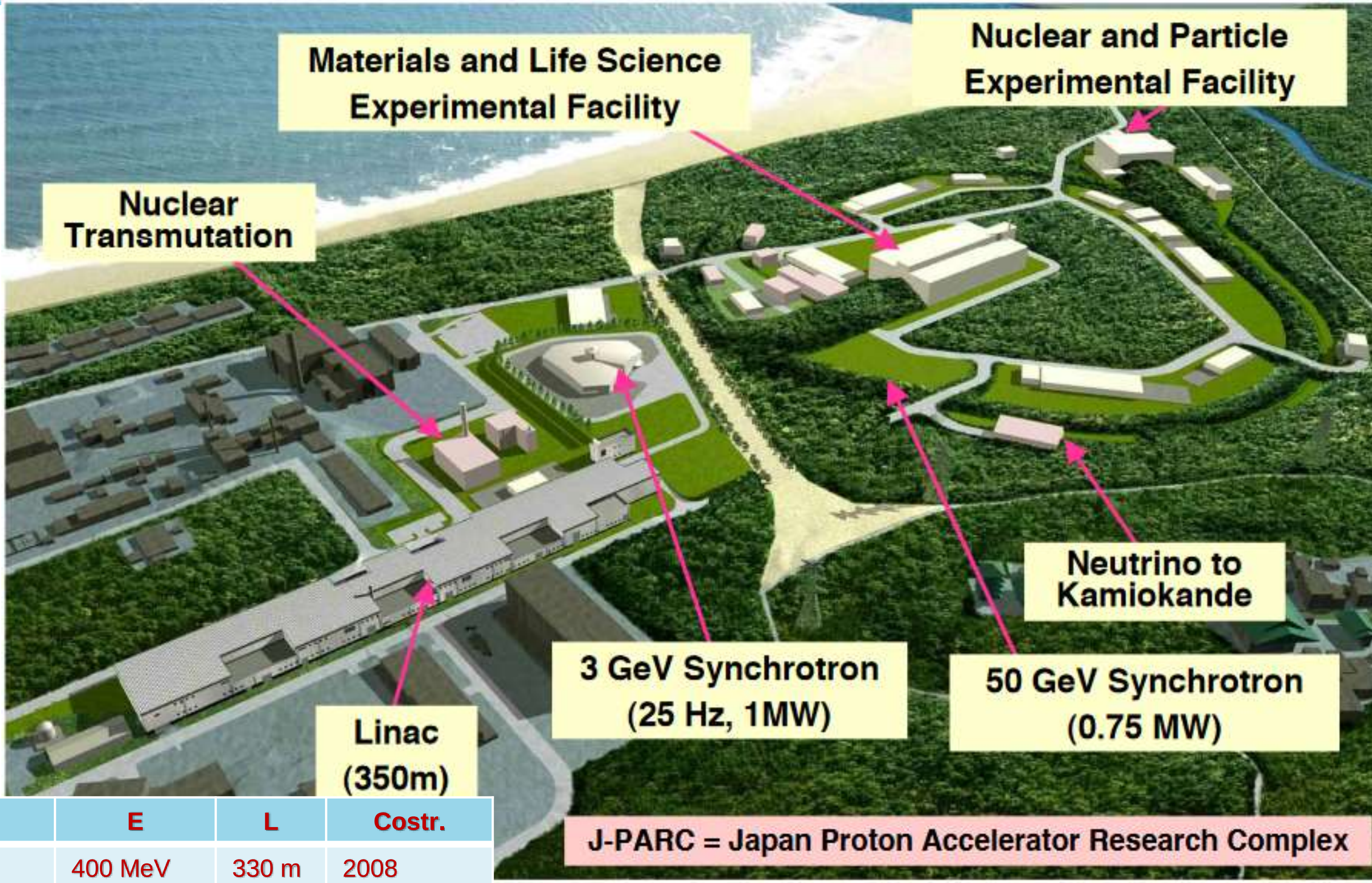


	E	L	Costr.
H- RFQ	0.75 MeV	2 m	2013
Linac	400 MeV	200 m	1970/93
Booster	8 GeV	500 m	1971
RR	8 GeV	3.3 km	1999
MI	120 GeV	3.3 km	1999
Delivery Ring	3.8-8 GeV	500 m	1985/2014
Beamlines	3-120 GeV	3.5 km	1970's-now
Upgr: PIP-II	800 MeV	240 m	2025
Upgr :PIP-III	8 GeV	500 m	2032
Upgr: beamlines	0.8-8 GeV	500 m	2025

Fermilab (2) – Many improvements plus *PIP I-II-III*

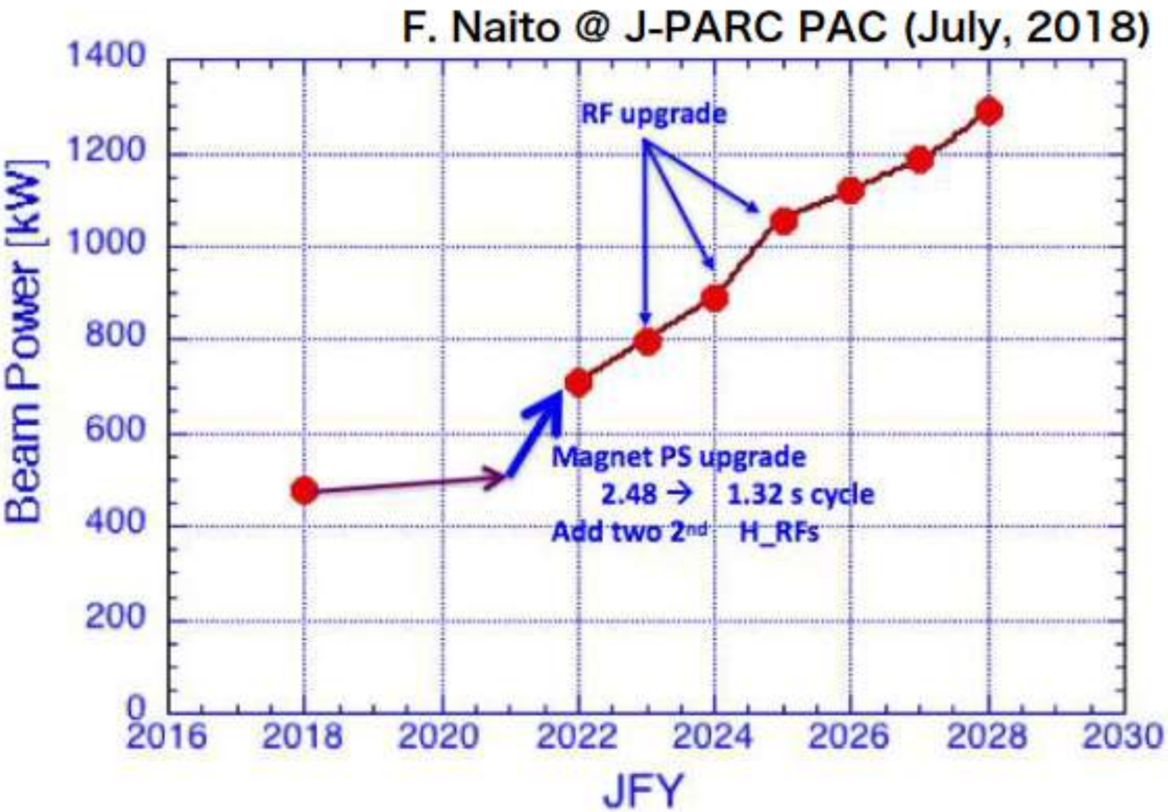


JPARC (1)



	E	L	Costr.
Linac	400 MeV	330 m	2008
RCS	3 GeV	350 m	2009
MR	30 GeV	1.6 km	2010
Beamlines	3-30 GeV	200 m	2009
Upgr: Power *f*N*			2020-28

JPARC (2) - Upgrades



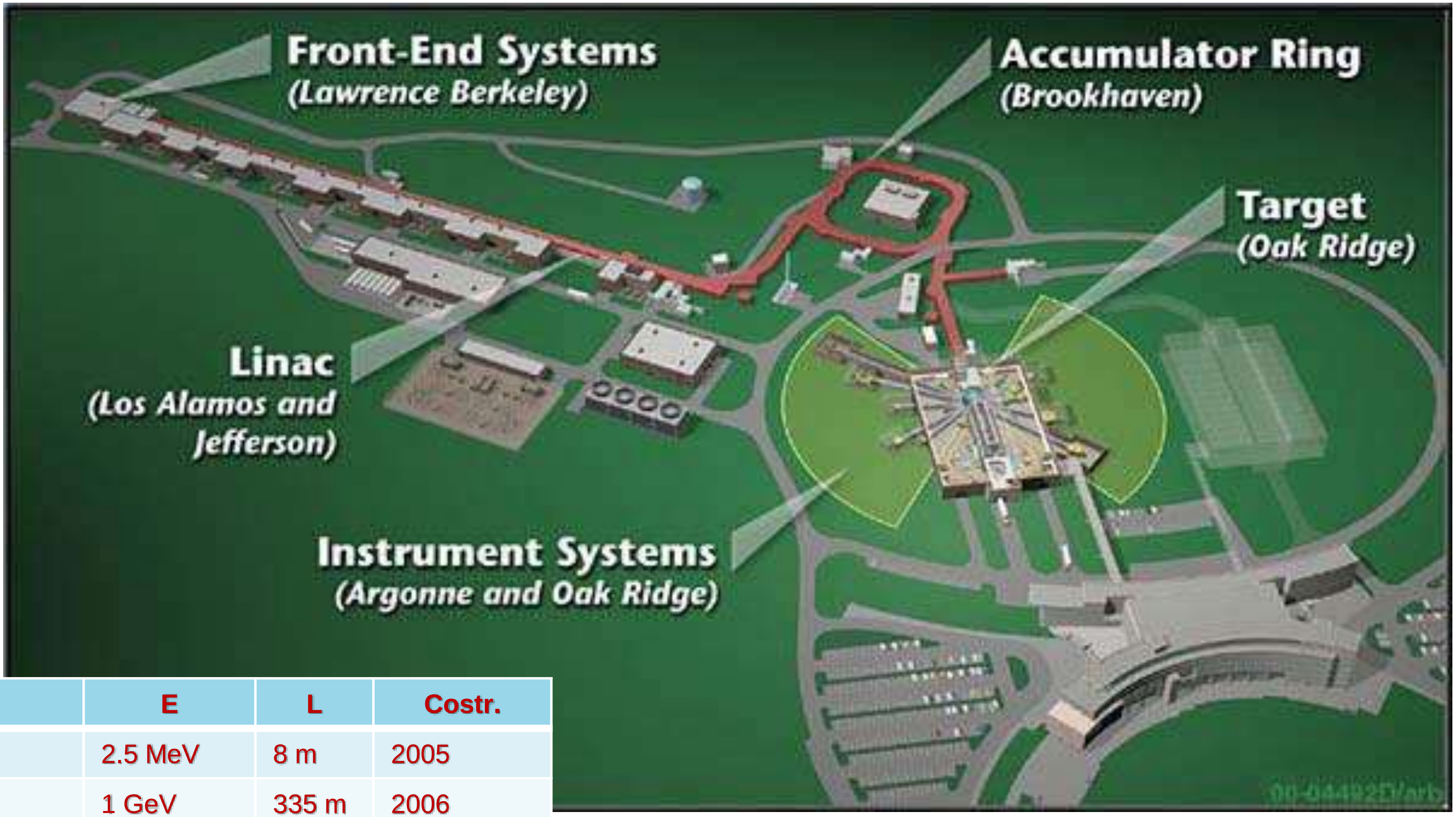
Higher rep rate:

1) MR magnet power supply upgrade
2) MR RF upgrade (High grad/PS)
3) MR Fast Extraction Kicker upgrade

Higher #p/p :

1) MR RF upgrade (PS)

SNS (1)



	E	L	Costr.
RFQ	2.5 MeV	8 m	2005
Linac	1 GeV	335 m	2006
Ring	1 GeV	250 m	2006
Beamlines	1 GeV	200 m	2006
Upgr: PPU	1.3 GeV		2025
Upgr: STS			2029

SNS(2) : Proton Power Upgrade

- Proton Power Upgrade project at the ORNL/SNS will double the proton beam power from 1.4 MW to 2.8 MW.
- This will be accomplished by a ~50% increase in beam current, from 25 to 38 mA and an increase in the final beam energy from 1.0 to 1.3 GeV.
- To achieve the current increase some warm linac RF systems will be upgraded to higher power :
  - upgrade DTL-4 and DTL-5 klystrons from 2.5MW to 3 MW
  - new resonant kicker charging system instead of DC
- To achieve the energy increase 7 CMs containing 28 high-β elliptical SRF cavities will be added to the end of the linac:
  - Plus many other things, like stripping foil, collimation, IBS loss control, gas stripping loss control, etc

SNS (3) : Second Target Station - Concept

- **Accelerator:** Accelerator modifications will increase the power of SNS; the existing target station will receive 50 proton pulses per second while 10 pulses per second will be redirected down a new transport line to the second target station.
- **Target System:** The proton pulse reaching the target will have one-fifth the footprint of and produce neutrons in a much smaller volume than those reaching the first SNS target. To manage volumetric heating, the tungsten target will rotate during use so that only 5 percent is active at any one time. Advanced moderators located adjacent to the active target region will lower the neutron energies to those required by the instruments.